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Does Hospital Competition Improve Efficiency? An Analysis of the Recent Market-Based Reforms to the English NHS

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Abstract
This paper uses a difference-in-difference estimator to test whether the introduction of patient choice and hospital competition in the English NHS in January 2006 has prompted hospitals to become more efficient. Efficiency was measured using hospitals' average length of stay (LOS) for patients undergoing elective hip replacement. LOS was broken down into its two key components: the time from a patient's admission until their surgery and the time from their surgery until their discharge. Our results illustrate that hospitals exposed to competition after a wave of market-based reforms took steps to shorten the time patients were in the hospital prior to their surgery, which resulted in a decrease in overall LOS. We find that hospitals shortened patients' LOS without compromising patient outcomes or by operating on healthier, wealthier or younger patients. Our results suggest that hospital competition within markets with fixed prices can increase hospital efficiency.

Keywords: Hospital Competition, Market Structure, Prospective Payment, Incentive Structure
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1. Introduction

There has been significant interest globally in sharpening the financial incentives within public services like health care and education in an effort to improve quality and efficiency. To that end, over the last decade, policy-makers in England have introduced sweeping reforms to the National Health Service (NHS) that have centered on expanding patient choice and hospital competition (Department of Health, 2005b). Previous research suggests that the recent introduction of hospital competition in the English NHS has catalyzed improvements in hospital quality (Cooper et al., 2010). This paper assesses the extent to which competition in the English NHS has increased hospital efficiency.

There were three central elements to the market-based reforms to the English NHS, which were implemented from 2002 onwards (Department of Health, 2002). First, beginning in 2002, the government introduced a fixed price, prospective reimbursement system known as Payment by Results (PbR) to pay for hospital care. That new reimbursement system became fully operational in 2005. Second, around the same time, the government took dramatic steps to diversity the hospital sector and increase hospitals' freedom from central control. Along those lines, the government actively encouraged private sector providers to enter the market and offer care to NHS patients alongside traditional NHS hospitals, in addition to rewarding high performing NHS hospitals with additional fiscal and managerial autonomy. Third, beginning in 2006, every NHS patient in England was given the opportunity to choose their secondary care provider if they required surgical care. Policy-makers hoped this increase in hospital competition within a market with fixed prices would incentivize hospitals to improve their quality and increase their efficiency in order to garner additional revenue (Department of Health, 2005b).

To analyze the impact of competition on hospital efficiency, we use a difference-in-difference estimator to test whether hospitals in located in less concentrated markets responded more aggressively to the new prospective reimbursement system and shortened their average, annual length of stay (LOS) for patients undergoing elective hip replacement after the introduction of hospital competition in January 2006. Often, because of the inadequacy of cost data in health services research, LOS is frequently used as a proxy for efficiency (Fenn and Davies, 1990; Martin and Smith, 1996). In England, since each additional bed day from 2006 onwards reduces hospitals' revenue by £248.00, providers faced significant incentives to discharge patients from the hospital more quickly. We examine whether or not those incentives spurred on changes in behaviour.

However, we are not exclusively interested in examining whether higher hospital competition was associated with lower LOS. Rather, we are interested in examining whether any changes we observe in LOS were driven by genuine improvements in hospital efficiency or instead were driven by hospitals selecting healthier patients for surgery or instead discharging patients 'sicker and quicker'. Ultimately, a patient's LOS is composed of two key components: 1) the time from the patient's admission until their surgery; and 2) the time from the patient's surgery until their discharge. The pre-surgery LOS is largely determined by actions taken by the hospital and for elective hip-replacement, is likely largely unrelated to patient characteristics. As a result, it should be a strong proxy for efficiency. In contrast, the post-surgery LOS is heavily dependent on patient characteristics which directly influence recovery time (Epstein et al., 1990; Martin and Smith, 1996; Sudell et al., 1991). However, any significant decrease in post surgery LOS could also be a sign of hospitals choosing to operate on healthier patients, or hospitals taking steps to discharge patients before it was clinically appropriate. Therefore, in this analysis, we examine whether the incentives created within the English NHS reforms created incentives that drove providers to quality skim in order to garner additional revenue, or instead prompted providers to take concrete steps to become more efficient.

Ultimately, we find that the NHS reforms prompted hospitals in the English NHS to become more efficient. Our results suggest that after being exposed to incentives created by competition from 2006 onwards, hospitals have reacted by reducing their annual LOS. Crucially, we also find that while hospitals cut down on the pre-surgery component of LOS, there were no statistically significant differences in the time from surgery to discharge between competitive and non-competitive hospitals, suggesting that hospitals facing greater competition did not discharge patients 'sicker and quicker'. We also found no evidence of hospitals choosing to operate on healthier or younger patients. Thus, our results suggest that hospital competition in England within a market with fixed prices led to marked improvements in hospital efficiency as opposed to implementation of quicker, inappropriate discharge policies.

This paper is structured as follows. Section 2 outlines the NHS reforms. Section 3 provides a review of the relevant literature related to hospital competition and the impact of introducing fixed price payment systems. Section 4 outlines our methodology and estimation strategy. Section 5 presents our results and section 6 includes our discussion and conclusion.

2. The NHS Reforms

The NHS reforms, introduced from 2002 onwards, involved significant changes to the way hospital care was paid for in England, gave patients a choice of their secondary health care providers, and diversified the supply of hospitals in the NHS (Department of Health, 2002). The reforms were all implemented on a rolling basis from 2002 onwards, and the key incentives from the reforms began significantly impacting providers from January 1st, 2006 onwards. Figure 1 is a timeline of the major events in the rollout of the NHS reforms.

In 2002, the Department of Health introduced Payment by Results (PbR), a new reimbursement system for financing hospital care in England (Department of Health, 2005c). The newly created system, which was fully operational for all elective care across England in 2005, paid providers a fixed, pre-determined price for each episode of care they delivered.[1] This development brought financing of hospital care in England in line with the payment mechanisms used in most of Europe, Australia and the United States (Street and Maynard, 2007).

Prior to the introduction of PbR, hospitals in England were paid based using different forms of contracts, which varied in their degree of specificity and sophistication (Chalkley and Malcomson, 1998; Raftery et al., 1996). In general, the contracts allowed regional bodies to a purchase a broad range of services from a particular provider with very little specificity on the volumes of activity or the case mix included in the agreement. The new PbR system made two significant changes to how hospital care in England was funded. First, it fixed prices nationally and precluded English hospitals from competing on prices. Second, it allowed purchasers to pay for each unit of care, rather than for predefined volumes of

[1] The PbR program was unveiled in 2002 and has been phased over time. In 2003/2004, the program began by paying for elective activity that was necessary to shorten waiting times, but was not covered by existing contracts. Initially, PbR only paid for care covered by 15 HRGs. In 2004/2005, the program was expanded to pay for all elective care in Foundation Trust (FT) hospitals, which were a subset of high-performing NHS hospitals. In 2005/2006, the program was fully implemented across the NHS for elective care and HRGs were used to pay for nearly all elective hospital activity delivered to NHS patients treated in NHS and non-NHS hospitals. From 2006 onwards, the system was expanded to pay for outpatient care and for non-elective inpatient hospital activity.

services that may or may not have been together (Department of Health, 2005c). This shift in policy created strong incentives for hospitals to provide more care, rather than less.

Under PbR, purchasers now pay for individual spells of activity that are defined from the time of a patient's admission to the hospital until their discharge. Prices for each episode for care were defined using Health Resource Groups (HRGs), which were modeled on diagnosis related groups (DRGs) from the US (Farrar et al., 2009).. Right now, there are approximately 600 HRGs that account for the bulk of elective and non-elective hospital care and the prices for the HRGs are based on average national costs and are adjusted for local wage rates and input costs.

At the same time as policy-makers introduced changes to how care was financed, the health service began paying for patients to receive care in private sector facilities in an effort to increase the range of choices available to NHS users (Department of Health, 2002). Beginning in 2003, the NHS helped coordinate and fund the development of Independent Sector Treatment Centers (ISTCs) which were structured to compete against traditional NHS hospitals and to provide elective surgery and diagnostic services. Between 2002 and 2008, 42 ISTCs opened across England and they are projected to eventually provide up to 15% of total elective care (Propper et al., 2006). Also, in an effort to encourage local innovation, the government gave high performing hospitals additional fiscal, clinical and managerial autonomy. Hospitals that earned additional autonomy were referred to as 'foundation trusts' (Department of Health, 2005a).

Alongside diversifying the supply-side and introducing a fixed price, prospective payment system, policy-makers also gave patients a choice of where they went for secondary care. Initially, the Government introduced pilot programs for patients waiting over six months of care for surgery. After the success of the pilots, patient choice was extended and beginning in January 2006, every patient in England was to be offered a choice of at least four providers (of which one option should have been private) for care when they were referred for planned hospital care (Department of Health, 2002; Department of Health, 2003; Department of Health, 2008).

Broadly, the reforms were supposed to create significant incentives for quality and efficiency in the NHS. Policy-makers hoped that the new reimbursement system would increase activity rates, increase efficiency, as well as encourage providers to compete on quality. As the reforms were being introduced, the central government paid particular attention to financial health of hospitals and providers were encouraged to generate annual surpluses, which they were able to reinvest into their facilities. If hospitals ran deficits, they often received cautionary phone calls from the central government and in extreme situations, had their senior management removed. This placed added pressure on providers to become more efficient.

Crucially, we view January 2006 as our 'policy-on' date. We view that as the key point when hospitals in England were exposed to the financial incentives created by patient choice, PbR and private sector providers who entered the market.

3. Literature Review and Hypothesis

The new PbR system is a per case, prospective payment system that strongly resembles the US Medicare Prospective Payment System (PPS) introduced in 1983 (Frank and Lave, 1985; Lave and Frank, 1990; Manton et al., 1993). Introducing prospective, fixed hospital reimbursement should clearly have a negative effect on patients' LOS because a hospital's net revenue per patient is decreased for each additional day of care they provide. Under PbR, hospitals are paid a fixed amount based on the patient's diagnosis, not on their actual cost of treatment, so hospitals face the full cost each additional day that a patient remains hospitalized (Cutler, 1995). Because the reimbursement costs in PbR are set at the national average, hospitals can maximize their revenue by reducing their LOS below national averages (Street and Maynard, 2007)

There is an expansive literature from various countries suggesting that per case, prospective payment systems generally lead to a reduction in LOS. In the US, several studies, including Feder et al. (1987), and Guterman and Dobson (1986) have found that the introduction of PPS in the US reduced LOS by between 3% and 10%. Similarly, Feinglass and Holloway (1991) and Kahn et al. (1990) found that PPS led to a drop in LOS of over 10%. Such significant drops in LOS prompted fears that PPS may have also led to concurrent drops in clinical quality. However, Cutler (1995) looked at outcomes for 67 diagnoses and found that PPS did not lead to lower clinical quality.

Evidence from the introduction of a new prospective hospital reimbursement in Israel in 1990 mirrored the experience observed in the US. Looking at outcomes for five procedures, Shmueli et al. (2002) found that the new reimbursement system was associated with a significant reduction in LOS, but it did not lead to any statistically significant changes in mortality. Likewise, after the Italian government introduced a DRG-based financing system in 1995, Louis et al. (1999) observed that LOS dropped, without having an adverse impact on mortality or readmission rates.

There is also evidence from the impact of PbR in England. In a recent study, Farrar et al. (2009) conducted a difference-in-difference analysis comparing various outcomes measures in Scotland and England from 2002 through 2006. Unlike England, Scotland did not introduce a prospective funding system from 2003 through 2006. As a result, the authors were able to treat Scotland as a quasi-control and estimate the impact that PbR had on quality, volume and costs in the English NHS. Farrar et al. (2009) found that in England, under a fixed price payment system, LOS fell more quickly and the proportion of day cases rose relative to Scotland. Their work suggests that PbR was highly successful at reducing unit costs in the NHS and driving down LOS. Echoing Cutler's (1995) results, Farrar found no association between PbR and changes in mortality or readmission rates.

While there is no empirical evidence available, there is reason to believe that hospitals facing greater competition will respond more aggressively to the introduction of a prospective payment system. Fixed price, prospective payment systems like PbR in England create two sorts of incentives for providers. First, because the marginal reimbursement rate for additional treatment is zero, there are strong incentives for providers to reduce LOS in order to maximize their revenue. This type of incentive should apply to all hospitals, regardless of the degree of competition they are facing. However, the second type of incentive created from PbR may have a more significant impact on hospitals located in less concentrated markets.

Prospective, fixed price reimbursement systems pay hospitals for their activity and, assuming the reimbursement rate is greater than the marginal cost of care, PbR encourages providers to increase their activity in order to generate additional revenue. However, hospitals located in monopoly markets likely have limited scope to expand their activity because they constrained by fixed levels of clinical demand within their catchment areas. In contrast, for hospitals located in competitive markets where a hospital's catchment area overlaps with other hospitals' catchment areas, there are clear opportunities for hospitals to significantly expand their activity by poaching other hospitals' patients. To expand their activity, hospitals therefore will take action to reduce the time patients are in the hospital so they can have more room for additional patients.

There is evidence that, with respect to clinical quality, hospitals located in less concentrated markets behave differently than hospitals located in monopoly markets when they are exposed to competition (Cooper et al., 2010; Kessler and McClellan, 2000; Propper et al., 2008). Emerging research looking at the impact of fixed price competition on clinical quality in the US and England suggests that in a market with fixed prices, competition catalyzes improvements in clinical performance. In a widely cited study examining the impact of market structure on quality, Kessler and McClellan (2000) looked at the impact of hospital competition in the US on AMI mortality for Medicare beneficiaries from 1985 to 1994. The authors simulate demand in order to create measures of competition that are not based on actual patient flows. They find that in the 1980s, the impact of competition was ambiguous, but in the 1990s, higher competition led to lower mortality. Using related methodology, Kessler and Geppert (2005) found that competition was not only associated with improved outcomes in their Medicare population, but it also led to more intensive treatment for sicker patients, and less intense treatment for healthier patients who needed less care.

In England, recent evidence examining the impact of the introduction of patient choice on clinical outcomes finds similar results. Cooper et al. (2010) use a modified difference-in-difference analysis to analyze mortality from heart attacks and find that hospitals located in competitive markets improved their mortality more quickly than hospitals located in less competitive markets after patient choice and hospital competition was introduced nationally in 2006. They find that from 2006 onwards, after the introduction of patient choice and hospital competition, mortality fell more quickly in hospitals facing greater competition. In that study, the authors find that their results remain consistent across a number of different measures of market structure.

This paper builds on this research and examines the impact of competition on hospital efficiency. More specifically, the paper tests whether or not hospitals located in less concentrated markets reacted more aggressively to PbR when hospital competition was introduced in the English NHS in January 2006. We test whether LOS was lower in hospitals facing greater competition after the introduction of a fixed price, prospective payment system. We hypothesize that hospitals facing greater competition will take additional steps to shorten their LOS because they have the potential to increase their activity levels in order to garner additional revenue.

4. Data, Measuring Competition and our Estimation Strategy

Data and our measurement of efficiency

This paper relies on patient-level Hospital Episodes Statistics (HES) data from 2002 through 2008 that are drawn from the NHS Commissioning Data Set. This is a large administrative data set, which records nearly every consultant episode.[2] This dataset includes a wide range of information on patients, providers and local area characteristics.[3]

Our analysis focuses on elective hip replacements with Office of Population, Census and Surveys Classification of Surgical Operations and Procedures 4th Edition (OPCS 4) codes of W37.1, W38.1 and W39.1.[4][5] We focus on elective hip replacements in this study because it is a high volume surgical procedure where there is little variation in clinical practice (Hamilton and Bramley-Harker, 1999). Further, while new clinical interventions in other specialties, like angioplasty for treating myocardial infarction, have become increasingly

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[2] Each HES record is a consultant episode, which we then collapsed to spells (admissions).
[3] Appendix 1 includes summary statistics for our sample.
[4] We did not include hip replacement revisions in our sample.
[5] Our analysis also integrates data on admissions for elective procedures (hip replacement, knee replacement, knee arthroscopy, cataract repair and hernia) for use in the construction of our competition indices.

more common in England over the last decade and have likely led to shorter lengths of stay and better outcomes, there has been very little change in how hip replacements are performed. As a result, the changes we observe in the length of stay for hip replacement patients likely will be driven by the NHS reforms, not by other advancements in medical care.

Our dependent variable of interest is hospitals' annual, average length of stay for patients admitted for an elective hip replacement between 2002 and 2008. Length of stay is measured as the time of a patient's admission to the time of their discharge. Our annual hospital-level LOS is the average LOS of all patients who underwent an elective hip replacement during the calendar year. There has been significant attention focused on LOS in the literature because often, in the absence of strong cost data, it can serve as a strong proxy for efficiency (Fenn and Davies, 1990; Martin and Smith, 1996). Ultimately, if quality can be maintained, a reduction in LOS will reduce the costs of carrying out a defined procedure. Even though previous research illustrates that LOS is strongly influenced by patient characteristics, even after controlling for patient characteristics, there is significant evidence that illustrates that there is expansive, unexplained variations in LOS between hospitals (Martin and Smith, 1996).

We believe that a key factor in successfully using LOS as a proxy for hospital efficiency is factoring out the influence of patient characteristics in how long a patient is in the hospital. As a result, in order to get a stronger proxy for hospital efficiency, we divided patients' length of stay in the hospital into two components. The first component of LOS, which we refer to as the pre-surgery LOS, is measured as the time from when the patient was admitted for care until their elective surgery was performed. For elective surgery, this component of LOS is likely not highly influenced by patient characteristics and should be highly influenced by hospital behavior. The second component of LOS that we measure is the post-surgery LOS, which is recorded as time from the surgery itself until a patient's discharge. Clearly, the literature suggests that this component of LOS should be heavily influenced by patient characteristics (Epstein et al., 1990; Martin and Smith, 1996; Sudell et al., 1991).

For our empirical analysis, we log transformed our various measures of LOS because they approximated log-normal distributions and because we expected the changes in length of stay to occur proportionately, rather than linearly. We limited our observations to patients ranging in age from 55 to 90 and we excluded observations where the LOS was in the highest 1% of our distribution.

At the hospital level, we know hospital site postcodes, and the NHS Trust to which the site belongs and have information on providers' annual activity levels. In addition, we are able to control for hospitals' annual 30-day mortality and readmission rates. Within this study, we use 30-day mortality in the community where deaths data are drawn from the Office of National Statistics (ONS). Most existing research on the NHS is at the hospital Trust level and typically uses the address of the Trust headquarters to define the location where patients received care. This is a very approximate basis for locating hospitals and constructing spatial competition variables. In practice, NHS trusts are usually composed of multiple smaller sites, which are sometimes separated by distances of up to 50km, and Trust headquarters are often not located where the Trust actually carries out clinical care. Trust-based competition indices thus miss out on important dimensions of inter-site competition both between and within Trusts. We are able to improve on this by using postcodes of the hospital site where the patient receives their treatment.[6]

[6] Site postcodes are missing in our data for up to 15% of the patient observations, but most of these cases with missing site codes come from patients treated at trusts that only actually had one site. For observations where the site postcode was missing and the Trust only had one site, we replace the missing site postcode with the

We use GP and hospital site postcodes to calculate distances between a patient's GP and the hospital where their secondary care was delivered. This distance is an important component in our analysis and is used as an input into our competition measures. For our main analysis, we use matrices of straight-line distances. We generated the GP-hospital origin-destination matrix using the Network Analysis tools from ArcGIS.

Our patient level data allow us to effectively risk-adjust for clinical severity by controlling for patient characteristics in our estimates. These patient characteristics include gender, age and Charlson comorbidity score (Charlson et al., 1978). We carry out our analysis at the hospital level, and control for annual changes in patient characteristics at individual hospital sites. The data suppliers use the patients' home address to link to residential area characteristics like urban density and socio-economic status. Socio-economic status is measured at the Census Output Area Level using the income vector of the 2007 Index of Multiple Deprivation (Communities and Local Government Department, 2009). For confidentiality reasons, the patient home addresses are not available for use in our analysis. However, we do have access to codes that identify the patient's GP and GP postcode. There are around 7600-7700 GP postcodes in each year in our data. Patients can usually (at the time relevant for our study) only register at a GP practice if they live in a GP's catchment area, so a patient's GP practice location serves as a strong proxy for a patient's home addresses.

Estimating competition

There is significant debate and discussion about how to measure hospital competition (Baker, 2001). Often the debate about how to measure competition centers on two key concerns: how to specifically quantify competition (which index to use) and how to define the market within which hospitals compete (Baker, 2001; Kessler and McClellan, 2000). The overarching concern when measuring hospital competition, particularly when it is going to be used to examine the relationship between competition and quality or competition and efficiency is the potential for endogeneity (Kessler and McClellan, 2000). Here, there is a risk that when competition is measured using actual patient flows, there may be a two-way relationship between competition and efficiency. For example, a high performing hospital may appear to be operating in a less competitive market because it has been able to attract market-share from its competitors or even drive them out of the market. Likewise, poorly performing providers may appear to be operating in more competitive markets because their lack of quality and efficiency has encouraged other competitors to enter the market and offer better services to patients at more reasonable prices. In what follows, we will outline how we estimate competition in this paper and discus the steps we take to mitigate against endogeneity between competition and efficiency.

When measuring competition, investigators often use a Herfindahl-Hirschman index (HHI) to describe and quantify the underlying market structure. The traditional HHI is defined as the sum of the squares of the market share of providers within a defined market, such that:

(1) $$hhi = \sum_{i=1}^{N} s_i^2 \ ,$$

where s_i is the market share of firm *i* in a market with *N* firms. The advantage of using an HHI to quantify competition is that it takes into account both the number of firms in the

Trust postcode. For the fewer than 2% of observations where there was a missing site postcode for a patient treated at a Trust with more than one site, we randomly assigned patients to sites within that Trust.

market and the relative size of the firms. However, there are fears that using an HHI introduces the possibility of endogeneity because if a firm in the market has very high quality or efficiency, it will also likely have a significant market-share. That itself will make the market look less competitive. To avoid this potential endogeneity, researchers often simply use the count of firms within the market to quantify competition. Within this paper, we use both counts and HHIs to measure competition and show that our results are robust across both measures.

In practice, within our estimators, we use the negative natural logarithm of an HHI based on hospitals' patient shares, where:

(2) $$nlhhi_j = -\ln \sum_{k=1}^{N} \left(\frac{n_k}{N_j} \right)^2 .$$

Here, *nk* is the number of procedures carried out at hospital site *k* within market area *j* and *Nj* is the total number of procedures carried out in market area *j*. This negative log transformation of the HHI is convenient because it increases with competition, with zero corresponding to monopoly and infinity to perfect competition. In addition, this estimation of the HHI is convenient because the negative natural log of the HHI is equal to the natural log of the number of equal sized providers in the market. That is,

(3) $$nlhhi_j = -\ln(hhi_j) = \ln\left(\frac{1}{hhi_j} \right) .$$

$$= \ln(\text{equivalent number equal sized providers})$$

So, for instance, our average HHI in our preferred estimation is 0 .79, which is equivalent to approximately 2 equal size providers in a patient's geographic market.

Once investigators decide how to measure competition within markets, the more pressing question is how to define the market areas in which hospitals compete. There are three often-used strategies to define the market over which hospitals compete, each with their respective strengths and weaknesses. First, researchers can use administrative boundaries to delineate their market boundaries. In England, in particular, this strategy is not appropriate because patients can travel outside of their administrative boundaries for care. A second strategy is for investigators define the market using a fixed radius drawn around a firm and then treat any firms which are located within that fixed radius market as a competitor. The advantage of a fixed radius market definition is that it is easy to compute. The down size is that it leads to significant urban rural bias and likely over-estimates competition in urban areas and under-estimates competition in rural areas. A third strategy often used in the literature is to quantify competition using a variable radius market. Here, the radius corresponds to a length that captures a fixed percentage of a hospital's patients. So, for instance, a hospital's market could be defined by a radius that captures 80% of a the hospital's patients. The advantage of using a variable radius definition of market size is that it is sensitive to urban rural differences. The central drawback of the variable radius measure is that it maybe potentially endogenous to quality. For example, a high quality hospital may draw patients from a greater distance than a low quality substitute. As a result, using a variable radius measure to define the hospital's size could lead to a correlation with the hospital's quality or efficiency.

In this paper, we define markets using a variable radius, but we make several key modifications aimed at thwarting endogeneity. First, we use a difference-in-difference estimator to assess the relationship between competition and quality. As we will discuss in the next section, this reduces the risk of endogeneity because we were not interested in the cross-sectional relationship between LOS and market structure, but rather we examine the interaction of time and market structure on LOS. Second, rather than centering our markets on hospitals, we center them on GP practices (which is where the choice of provider gets made). Third, we use a time-fixed competition measure and estimate competition and radius size from 2002 through 2005, before patient choice and hospital competition were formally introduced. As a result, the size of our market area is determined mainly by historical precedence and not heavily influenced by clinical performance or patient choices. Fourth, we calculate our competition measures as a composite of the competition measures for several surgical procedures. Fifth, we aggregate our GP-level competition measures up to the hospital level, so that a hospital's calculated competition is the average of the competition measured in the GPs' markets that refer to a particular hospital.

Details on our methodology for constructing our market definitions are as follows. Consider an elective procedure, e.g. hip replacements, in one year, e.g. 2002. We first use matrices of patient flows from GPs to hospitals for hip replacement in 2002 to deduce GP centered market areas. Specifically, we find the radius that represents the 95th percentile of distance traveled from a GP to hospitals for hip replacements in 2002. This radius defines the limit of the *feasible* choice set for patients at this GP in 2002. Note, only one patient needs to attend a hospital site for that site to modify the GP-centered market radius. We then compute a *nlhhi* based on *all* hospitals providing hip replacements within this GP's market area, regardless of whether this GP actually refers patients to all of these hospitals. This process is repeated for all GPs, all years 2002-2005 and all five key elective procedures – arthroscopy cataract repair, hernia repair, hip replacement, and knee replacement. A single elective *nlhhi* is calculated for each GP and year as a weighted average of the procedure-specific *nlhhi*, where the weights are proportional to the volume of patients in each procedure category. This pre-reform competition is then collapsed into a single, time fixed measure and aggregated up to the hospital-level. Thus, each hospital is assigned a *nlhhi* that is then the average of the level of competition in each GPs market who refers to that hospital.

In addition, we also calculate a measure of primary school competition in an identical manner, which we use in a placebo test later in the paper.

Estimation strategy

In our analysis, we rely on two DiD estimators to test whether hospitals located in less concentrated markets were able to increase their efficiency after they were exposed to hospital competition from January 1, 2006 onwards. Whereas the bulk of the existing research on hospital competition relies on analyzing a cross sectional relationship between measured competition and quality, we use our estimates of competition to determine which hospital markets were 'treated' and therefore exposed to the full force of the NHS market-based reforms after they took effect in 2006. This is a further step to thwart endogeneity between our competition measures and LOS. Similar DiD estimation strategies have been used in other contexts, for example, in the evaluation of the employment effects of the minimum wage (Card, 1992), as well as to study the earlier 1990s internal market NHS reforms (Propper et al., 2008).

In our first estimator, we use a traditional DiD framework with a binary post-treatment (post 2005) indicator variable interacted with a continuous treatment variable (our competition measure). In practice, this takes the form:

(4) $$LOS_{jt} = \alpha + \beta_1 nlhhi_j + \beta_2 Post_j + \beta_3 (Post_j * nlhhi_j) + \gamma' controls_{ijkt} + error_{ijkt} .$$

Here, the *Post* variable is equal to 1 if the year is 2006 or later and *nHHIi* is our measure of market-concentration. In (4), we are interested in the coefficient associated with β_3, which is the interaction of *Post* and *nlhhi* and illustrates the impact of higher competition after the reforms were put in place. Within (4), we include hospital fixed effects and also control for a range of controls including hospitals' annual activity levels, their annual gender composition, the annual average of the Charlson co-morbidity score of their patients, the average annual age of their patients, the average annual socio-economic status of their patients, and the hospital's annual 30-day mortality[7] and readmission rates.

In addition to (4), we also use a modified DiD estimator where our *nlhhi* is interacted with year dummies. This framework allows us to get a more nuanced picture of the changes induced in LOS and the year-on-year impact of competition on LOS that illustrate more precisely when there was a time break in the LOS trends. Using our modified DiD framework, our estimation takes the form:

(5) $$\begin{aligned} LOS_{jt} &= \alpha + \beta_1 t + \beta_2 nlHHI_j + \beta_3 (nlHHI_j * 2003) + \beta_4 (nlHHI_j * 2004) + \beta_5 (nlHHI_j * 2005) ... \\ &+ \beta_8 (nlHHI_6 * 2008) + \gamma' controls_{ijkt} + error_{ijkt} \end{aligned}$$

Here, coefficient β_1 captures year dummies for 2003 – 2008. Coefficient β_2 captures the *nlhhi* for hospital *j* and β_3 , β_4, β_5 , β_6, β_7 , β_8 are similar to the interaction term in a traditional DiD estimator and capture the impact of competition on LOS in 2003, 2004, 2005, 2006, 2007 and 2008. The coefficient β_2 is informative in that it provides the basis for the test of whether or not there are pre-policy differences in LOS for hospitals located in high versus low concentration markets. The existence of pre-policy differences in LOS would undermine the credibility of our DiD strategy. The controls included in (5) were hospitals' annual average age of patients, their gender distribution, their patients' average socio-economic status, and their average co-morbidity. In addition, we included hospital fixed effects as well as controls for hospitals' annual activity levels, 30-day mortality[8] for hip replacements and thirty-day readmission rates for hip replacements.

Instrumental variable estimation

In addition to using HHIs and counts to quantify competition, we also use an instrumented measure of competition. Recall that two main causes for concern related to endogeneity are: a) the *nlhhi* in (4) and (5) is potentially endogenous to LOS in each hospital market because of the dependence of the market radius and hospital shares on LOS; and b) that the coefficients on the interaction between competition and time that we use in our estimator may pick up basic urban-rural differences that specifically related to hospital competition differences.

To address these issues, we provide IV estimates using an instrument for competition based on variation in distances from a patient's GP to the four nearest hospitals. These GP-based measures are then aggregated up to each hospital. We view variation in the GP-to-hospital distances as an exogenous measure of completion because if a patient is registered at a GP where there is a high variance in the distance to local hospitals, each substitution from one hospital to another will have high transportation costs for the patient. This makes the

[7] Our 30-day mortality for hip replacement included deaths outside of the hospital.
[8] Our 30-day mortality for hip replacement included deaths outside of the hospital.

patient less likely to exercise choice and as a result, creates less competitive pressure on local hospitals. For example, we assume patients registered at a GP with its four nearest hospitals located at 1km, 12km, 27 km and 31km away from the GP will have a stronger pull to their nearest hospital than a patient whose GP was located 12km, 15km 17km, and 17km from its four nearest hospitals, despite the fact that the average distance to the nearest four providers is the same in both cases. Aggregated up to the hospital level, a hospital whose catchment area has significant variation in the distances the patients have to travel to get care will likely face less competition than a hospital in a market where patients have clear substitutes for care and little variation in the distance they need to travel.

We therefore use the variation in GP-site distance (amongst the nearest four sites) aggregated to the hospital level, as an instrument for *nlhhi*, conditional on the mean distance to hospitals. The idea here is similar to that of predicting hospital shares from exogenous variables implemented in Kessler and McClellan (2000). However, we implement a more traditional IV, avoiding their non-linear 1st stage prediction and predicting competition from implicit travel costs, not patient demographics.

5. Results

Our analysis was conducted on 290,854 elective hip replacements, performed on NHS patients age 55 through 90, from 2002 to 2008. During this period, the procedures were performed at 277 unique site locations for patients who were registered at 8126 GP practices across England. In our analysis, efficiency is measured by a patient's length of stay in the hospital for elective hip replacement. As we have discussed, we separated length of stay into two components. The first component of length of stay is measured from the time of a patient's admission until their surgery. The second component is measured from their surgery until their discharge. During this period, patients were in the hospital for an average of 7.9 days for a hip replacement of which 92% of time spent in the hospital during the admission occurred after the patients' surgery was performed.

Figure 2 illustrates the change in overall, pre- and post- LOS from 2002 through 2008. Overall LOS and post-surgery LOS fell steadily during this time period, though the rate of decline begins to slow in 2007. This is consistent with previous research, which has found that the introduction of PbR led to shorter waiting times in England in comparison with Scotland (Farrar et al., 2009). In contrast, pre-surgical LOS hovers at approximately 1 day from 2002 through 2005, but begins to fall from 2006 onwards. Each year, there is significant variation in pre-surgery, overall and post-surgery LOS between hospitals suggesting that there is scope for underperforming hospitals to increase their efficiency.

Figures 3, 4, and 5 show the changes in overall, pre-surgery and post-surgery LOS for hospitals located in the most competitive, somewhat competitive, and least competitive markets. As figures 3 and 5 illustrate, the degree of competition in the hospital market had little bearing on its overall or post-surgical LOS. There is a uniform decrease in overall and post-surgical LOS regardless of the underlying hospital market structure. However, as figure 4 illustrates, market structure appears to have a significant effect on the pre-surgery LOS. Pre-surgical LOS in hospitals facing the most significant competition drops at a significantly faster rate than it does in hospitals located in somewhat and less competitive markets. In addition, there is a significant increase in the rate of decrease from 2006 onwards, after hospitals in England were exposed to hospital competition.

Table 1 presents the least-squared estimates of (4), which is our traditional DiD estimator. This specifications includes controls for patient characteristics, hospital fixed effects and annual hospital 30-day mortality and readmission rates. Here, the interaction term illustrates that from January 2006 onwards (our post reform period), higher competition was associated with lower overall LOS. Table 2 presents least-squared estimates of (4) where LOS is broken down into its two key components: pre-surgery and post-surgery LOS. Results from Table 2 illustrate that it is likely changes in pre-surgery LOS which are driving the reductions we observe in overall LOS. In Table 2, the interaction between competition, measured as the *nlhhi,* and the post reform dummy is only significant for the pre-surgery LOS. The interaction term associated with post-surgery LOS is negative, but not significant.

Table 3 presents the least-squared estimates of (5) where competition is measured using our variable radius HHI.[9] This is our preferred specification of (5) and includes controls for patient characteristics, hospital fixed effects, as well as hospital 30-day readmission rates and 30-day mortality rates. The year point estimates from Column (1), (2) and (3), mirror our findings in Figure 2 and echo results from Table 1. Pre-surgery LOS declined from 2006 onwards and overall LOS and post-surgery LOS fell steadily over the entire period. Crucially, our estimates presented in Column 1 in Table 3 suggests that after hospitals were exposed to competition in January 2006, hospitals located in less concentrated markets had shorter pre-surgery LOS than hospitals located in more concentrated markets. These decreases hospitals located in less concentrated markets made in pre-surgery LOS translated into decreases in overall LOS that were statistically significant in 2006. Interestingly, at the same time as hospitals facing greater competition took steps to shorten their pre-surgery LOS, there were no statistically significant reductions in post-surgery LOS suggesting that hospitals facing added competition did not discharge patients sicker and quicker. In addition, there was no significant association between the competition * year interactions and pre-surgery, overall or post-surgery LOS prior to 2006.

It is also worthwhile to note that the coefficients on baseline competition measure were not significant in any of our estimates. This illustrates that there was not a differences in pre-surgery, overall or post-surgery LOS between hospitals located in concentrated versus non-concentrated markets. This validates the assumptions underpinning our DiD estimator.

Table 4 presents least-squared estimates of (5) where competition is measured as the count of hospitals located within a variable radius market. Recall that this market-measure does not take into account the relative size of hospitals within the markets. In this estimation, our use of hospital counts serves as a robustness check on our use of an HHI to quantify market concentration. The results in Table 4 echo the results we observe in Table 3. We find that overall and post-surgery LOS decline steadily from 2002 though 2008. In addition, we find that hospitals located in less concentrated markets had lower pre-surgery LOS than hospitals located in more concentrated markets after hospitals were exposed to the incentives created by PbR and competition in 2006. At the same time, there were no significant differences in post-surgery LOS that were driven by differences in market structure. We find a less strong association between competition and overall LOS than we observed when market concentration was quantified using an HHI, though this likely is driven by the fact that pre-surgery LOS accounts for such a small percentage of overall LOS.

Table 5 presents our placebo test with estimates of (5) where competition is measured as the market structure within primary schools in England. The placebo test serves to validate that our estimates of hospital competition are not simply picking up spurious associations with urban density, which would also be captured in our school competition estimates. When we estimate (5) substituting school competition for hospital competition, we find no significant associations between our *nlhhi* * year interactions and pre-surgery, overall or post-surgery LOS.

[9] Appendix 2 presents the fully expanded results for Table 3.

Table 6 presents estimates of (5) where patient characteristics are substituted for LOS and serve as the dependent variables. These estimates represent a test of whether the results we capture in Table 3 and Table 4 are driven by changes in hospital efficiency, or instead reflected hospitals actively cream-skimming, or other broad changes in hospitals' patient case mix. Crucially, there were no significant associations between market-structure and patient morbidity (measured using the Charlson index of co-morbidity), age or the income vector of the 2007 Index of Multiple Deprivations. Estimates from Column (1), (2) and (3) from Table 6 illustrate that any changes in pre-surgery and overall LOS likely were not driven by hospitals operating on healthier, wealthier or younger patients. Interesting, in 2006, after the introduction of competition, hospitals located in less concentrated markets appeared to attract patients from higher socio-economic groups and the coefficient associated with the interaction between our 2006 year dummy and competition is nearly significant ($p = 0.05$). Given that there were no concurrent changes in age or co-morbidity, this likely did not influence our results. However, since 2006 was the first year of formal choice, this coefficient may be capturing the a greater proclivity among the middle and upper class to exercise 'choice' and travel further for care.

Instrumental variable estimation results

Table 7 presents our instrumental variables estimates of (5). Here, we instrument for market-structure using the variation in the straight line distance from each GP to the nearest four hospitals who perform hip replacements and aggregate up to the hospital level. The F-Tests on our instruments are significant ($p < 0.0001$).[10] The results for our IV estimates of (5) presented in Table 7 are similar to the results we obtained in our preferred specification presented in Table 3. The IV estimates in Table 7 demonstrate that from 2006 onwards, after hospitals were exposed to competition, hospitals located in less concentrated markets shorted their pre-surgery LOS more than hospitals located in more concentrated markets. At the same time, there was no statistically significant difference in post-surgery LOS that was driven by differences in hospitals' underlying market structure. The magnitude of the coefficients in our IV estimates are nearly double those presented in our preferred specification (Table 7 versus Table 3), although a Hausman test indicates that there is no statistically significant differences between the IV and OLS coefficients. As such, there is no evidence from the IV estimates presented in Table 7 that it is endogeneity between market structure and LOS that is driving our central findings.

6. Discussion and Conclusion

The main thrust of English health policy over the last five years has focused on increasing patient choice and hospital competition within a market with fixed prices. These market-based reforms within the English NHS have prompted significant academic and ideological debate (Dixon, 2009; Hunter, 2009; Le Grand, 2009). Previous research has found that these reforms led to higher clinical quality (lower mortality from acute myocardial infarctions) (Cooper et al., 2010). This paper uses a modified difference-in-difference estimator to examine whether or not hospital competition led to improvements in efficiency, which we proxy using patients' pre-surgery LOS for elective hip replacement.

There is ample reason to believe that competition will create incentives for hospitals to become more efficient. In England, the newly introduced fixed-price reimbursement

[10] The F-statistics on our IV estimates of (4) with pre-surgery LOS serving as the dependent variable are 62,732.75, 50131.67, 62547.78, 2318.92, 1346.70, and 44303.90, 6022.63 respectively.

system rewards hospitals for increasing their activity. In markets where hospitals are not constrained by fixed levels of clinical demand and have the potential to increase their activity, competition likely will spur hospitals to reduce their LOS in order to allow them to operate on more patients.

In testing this hypothesis we find that after hospitals were exposed to competition in 2006, hospitals which were located in less concentrated (more competitive markets) shortened their pre-surgery LOS more than hospitals located in concentrated markets. In addition, there were no differences in post-surgery LOS that were driven by market-structure and nor was their any evidence of cream-skimming. Therefore, our results suggest that after being exposed to competition, hospitals located in competitive markets took steps to improve their efficiency without compromising patient care or avoiding treating high-risk patients. These findings are consistent with previous research which has highlighted that during this period, hospitals located in more competitive markets had better hospital management (Bloom et al., 2010).

More broadly, this research illustrates that firms' underlying market-structure influences their reaction to changes in payment systems. Previous empirical research has found that a shift to prospective, fixed priced payments systems has led to a reduction in LOS. We have found that have found that firms located in more competitive markets react even more strongly to fixed price reimbursement systems because they have the additional opportunity to expand their market-share and increase their activity, which in the long term, will lead to higher revenue.

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Table 1: Least squared estimate of (4) where dependent variable is hospitals' overall LOS

	Coef. (Standard Error)
Post	-0.1764*** (0.0178)
nlhhi	0.0269 (0.1305)
Post * *nlhhi*	-0.0486* (0.0231)
Hospital Fixed Effects	Yes
R2	0.69
Obs	1518

Patient characteristics: average annual patient age; average annual patient socioeconomic status measured using the income component of the 2007 Index of Multiple Deprivations; patient gender; and average annual patient Charlson comorbidity score.

Hospital characteristics: Number of procedures carried out at each hospital annually; annual hospital 30-day hip replacement mortality; and annual hospital 30-day readmission rate.

Standard errors are clustered on hospital sites.

* Significant at 5% level; ** Significant at 1% ,*** Significant at 0.1%

Table 2: Least squared estimate of (4) where dependent variable is overall length of stay where the dependent variable is hospitals' average pre- and post-surgery LOS

	(1) Pre-surgery LOS	(2) Post-Surgery LOS
	Coef. (Standard Error)	Coef. (Standard Error)
Post	-0.1228*** (0.0312)	-0.1596*** (0.0236)
nlhhi	-0.2107 (0.2251)	0.2725 (0.2749)
Post * *nlhhi*	-0.0762* (0.0355)	-0.0360 (0.0285)
Hospital Fixed Effects	Yes	Yes
R2	0.64	0.69
Obs	1518	1518

Patient characteristics: average annual patient age; average annual patient socioeconomic status measured using the income component of the 2007 Index of Multiple Deprivations; patient gender; and average annual patient Charlson comorbidity score.

Hospital characteristics: Number of procedures carried out at each hospital annually; annual hospital 30-day hip replacement mortality; and annual hospital 30-day readmission rate.

Standard errors are clustered on hospital sites.

* Significant at 5% level; ** Significant at 1% ,*** Significant at 0.1%

Table 3: Least squared estimates of (5), where competition is measured as the negative natural log of the HHI within a variable radius market

Dependent Variable	**(1) Pre-Surgery LOS**	**(2) Overall LOS**	**(3) Post-Surgery LOS**
	Coef. (Standard Error)	Coef. (Standard Error)	Coef. (Standard Error)
2003 * *nlhhi*	-0.0273	-0.0162	-0.0131
	(0.0191)	(0.0155)	(0.0196)
2004 * *nlhhi*	-0.0379	-0.0210	-0.0088
	(0.0281)	(0.0222)	(0.0278)
2005 * *nlhhi*	-0.0681	-0.0385	-0.0202
	(0.0402)	(0.213)	(0.0289)
2006 * *nlhhi*	-0.1024*	-0.0777*	-0.0571
	(0.0413)	(0.0256)	(0.0290)
2007 * *nlhhi*	-0.1195*	-0.0762**	-0.0551
	(0.0479)	(0.0281)	(0.0305)
2008 * *nlhhi*	-0.1037*	-0.0474	-0.0276
	(0.0518)	(0.0351)	(0.0453)
2003	0.0126	-0.0460**	-0.0511**
	(0.0147)	(0.0130)	(0.0155)
2004	-0.0031	-0.0966***	-0.1072***
	(0.0227)	(0.0184)	(0.0209)
2005	0.0170	-0.1544***	-0.1900***
	(0.0334)	(0.0200)	(0.0289)
2006	-0.0350	-0.1930***	-0.2074***
	(0.0346)	(0.0213)	(0.0240)
2007	-0.1270*	-0.2670***	-0.2640***
	(0.0416)	(0.0247)	(0.0288)
2008	-0.2269***	-0.3540***	-0.3280***
	(0.0476)	(0.0283)	(0.0388)
nlhhi	-0.1165	0.1137	0.3413
	(0.2184)	(0.1123)	(0.2498)
Hospital Fixed Effects	Yes	Yes	Yes
N	1518	1518	1526
R2	0.69	0.80	0.75

Patient characteristics: average annual patient age; average annual patient socioeconomic status measured using the income component of the 2007 Index of Multiple Deprivations; patient gender; and average annual patient Charlson comorbidity score.

Hospital characteristics: Number of procedures carried out at each hospital annually; annual hospital 30-day hip replacement mortality; and annual hospital 30-day readmission rate.

Standard errors are clustered on hospital sites.
* Significant at 5% level; ** Significant at 1% ,*** Significant at 0.1%

Table 4: Least squared estimates of (5), where competition is measured as the count of hospitals within a variable radius market

Dependent Variable	(1) Pre-Surgery LOS	(2) Overall LOS	(3) Post-Surgery LOS
	Coef. (Standard Error)	Coef. (Standard Error)	Coef. (Standard Error)
2003 * *Count*	-0.0037	-0.0016	-0.0010
	(0.0020)	(0.0018)	(0.0024)
2004 * *Count*	-0.0013	-0.0016	-0.0016
	(0.0028)	(0.0023)	(0.0028)
2005 * *Count*	-0.0074	-0.0037	-0.0018
	(0.0043)	(0.0022)	(0.0031)
2006 * *Count*	-0.0103*	-0.0067*	-0.0049
	(0.0045)	(0.0027)	(0.0031)
2007 * *Count*	-0.0125*	-0.0052	-0.0032
	(0.0052)	(0.0028)	(0.0033)
2008 * *Count*	-0.0136*	-0.0043	-0.0008
	(0.0054)	(0.0039)	(0.0050)
2003	0.0136	-0.0488***	-0.0541***
	(0.0128)	(0.0126)	(0.0149)
2004	-0.0262	-0.1032***	-0.1025***
	(0.0204)	(0.0150)	(0.0194)
2005	0.0075	-0.1618***	-0.1940***
	(0.0290)	(0.0176)	(0.0252)
2006	-0.0524	-0.2138***	-0.2230***
	(0.0298)	(0.0194)	(0.0210)
2007	-0.1439***	-0.2956***	-0.2901***
	(0.0360)	(0.0223)	(0.0246)
2008	-0.2263	-0.3657***	-0.3445***
	(0.0403)***	(0.0246)	(0.0315)
Count	-0.0137	0.0161	0.0488
	(0.0294)	(0.0120)	(0.0286)
Hospital Fixed Effects	Yes	Yes	Yes
N	1518	1518	1518
R2	0.69	0.80	0.69

Patient characteristics: average annual patient age; average annual patient socioeconomic status measured using the income component of the 2007 Index of Multiple Deprivations; patient gender; and average annual patient Charlson comorbidity score.

Hospital characteristics: Number of procedures carried out at each hospital annually; annual hospital 30-day hip replacement mortality; and annual hospital 30-day readmission rate.

Standard errors are clustered on hospital sites.
* Significant at 5% level; ** Significant at 1% ,*** Significant at 0.1%

Table 5: Placebo test. Least squared estimates of (5), where competition is measured as the *nlhhi* of primary schools within a variable radius market

	(1)	(2)	(3)
Dependent Variable	**Pre-Surgery LOS**	**Overall LOS**	**Post-Surgery LOS**
	Coef.	Coef.	Coef.
	(Standard Error)	(Standard Error)	(Standard Error)
2003 * *nlhhi_school*	-0.0008	-0.0060	-0.0092
	(0.0097)	(0.0071)	(0.0095)
2004 * *nlhhi_school*	0.0039	-0.0037	-0.0022
	(0.0142)	(0.0094)	(0.0121)
2005 * *nlhhi_school*	-0.0125	-0.0139	-0.0069
	(0.0204)	(0.0115)	(0.0192)
2006 * *nlhhi_school*	-0.0091	-0.0139	-0.0118
	(0.0217)	(0.0139)	(0.0143)
2007 * *nlhhi_school*	0.0079	-0.0006	-0.0036
	(0.0253)	(0.0140)	(0.0142)
2008 * *nlhhi_school*	-0.0070	-0.0271	-0.0279
	(0.0285)	(0.0306)	(0.0347)
2003	-0.0046	-0.0344	-0.0263
	(0.0335)	(0.0271)	(0.0344)
2004	-0.0469	-0.0963**	-0.1045*
	(0.0520)	(0.0367)	(0.0420)
2005	0.0122	-0.1289**	-0.1791*
	(0.0765)	(0.0436)	(0.0737)
2006	-0.0770	-0.1967***	-0.2082***
	(0.0810)	(0.0532)	(0.0532)
2007	-0.2486**	-0.3219***	-0.2949***
	(0.0951)	(0.0544)	(0.0546)
2008	-0.2811	-0.2831**	-0.2411*
	(0.1082)*	(0.1046)	(0.1204)
nlhhi_school		-0.0638	0.0331
	-0.0661	(0.0751)	(0.1101)
Hospital Fixed Effects	Yes	Yes	Yes
N	1518	1518	1518
R2	0.68	0.80	0.74

Patient characteristics: average annual patient age; average annual patient socioeconomic status measured using the income component of the 2007 Index of Multiple Deprivations; patient gender; and average annual patient Charlson comorbidity score.

Hospital characteristics: Number of procedures carried out at each hospital annually; annual hospital 30-day hip replacement mortality; and annual hospital 30-day readmission rate.

Standard errors are clustered on hospital sites.
* Significant at 5% level; ** Significant at 1% ,*** Significant at 0.1%

Table 6: Estimates of (5) with patient characteristics serving as the dependent variable

Dependent Variable	(1) Charlson Co-Morbidity Score	(2) Age	(3) IMD 2007 Income Component
	Coef. (Standard Error)	Coef. (Standard Error)	Coef. (Standard Error)
2003 * *nlhhi*	-0.0289	0.0143	-0.0502
	(0.0232)	(0.2625)	(0.0415)
2004 * *nlhhi*	-0.0288	-0.0223	-0.0193
	(0.0441)	(0.2545)	(0.0533)
2005 * *nlhhi*	-0.0128	0.1842	-0.0617
	(0.0368)	(0.2766)	(0.0477)
2006 * *nlhhi*	0.0175	0.0686	-0.1003
	(0.0481)	(0.3161)	(0.0509)
2007 * *nlhhi*	-0.0412	-0.2594	-0.0321
	(0.0379)	(0.2901)	(0.0504)
2008 * *nlhhi*	-0.0428	0.4748	-0.1028
	(0.0395)	(0.2758)	(0.0605)
2003	0.0490*	0.1921	0.0030
	(0.0233)	(0.2009)	(0.0321)
2004	0.0753	0.2924	-0.0563
	(0.0435)	(0.1957)	(0.0465)
2005	0.0840**	0.2535	-0.0204
	(0.0259)	(0.2194)	(0.0389)
2006	0.0523	0.4380	-0.0038
	(0.0418)	(0.2514)	(0.0444)
2007	0.1570***	0.8167**	-0.0893
	(0.0307)	(0.2729)	(0.0521)
2008	0.2104***	0.5436*	-0.0523
	(0.0326)	(0.2613)	(0.0537)
nlhhi	-0.0973	-2.4275	0.2961
	(0.2175)	(1.5383)	(0.03395)
Hospital Fixed Effects	Yes	Yes	Yes
N	1518	1518	1518
R2	0.57	0.61	0.91

Patient characteristics: average annual patient age; average annual patient socioeconomic status measured using the income component of the 2007 Index of Multiple Deprivations; patient gender; and average annual patient Charlson comorbidity score.

Hospital characteristics: Number of procedures carried out at each hospital annually.

Standard errors are clustered on hospital sites.

* Significant at 5% level; ** Significant at 1% ,*** Significant at 0.1%

Table 7: IV estimates of (5)

Dependent Variable	(1) Pre-Surgery LOS	(2) Overall LOS	(3) Post-Surgery LOS
	Coef. (Standard Error)	Coef. (Standard Error)	Coef. (Standard Error)
2003 * *IV_nlhhi*	-0.0341	-0.0422	-0.0682
	(0.0444)	(0.0359)	(0.0532)
2004 * *IV_nlhhi*	-0.0858	-0.0060	0.0191
	(0.0460)	(0.0306)	(0.0436)
2005 * *IV_nlhhi*	-0.1165	-0.0196	0.0026
	(0.0755)	(0.0488)	(0.0757)
2006 * *IV_nlhhi*	-0.1521	-0.0532	-0.0125
	(0.0777)	(0.0655)	(0.0825)
2007 * *IV_nlhhi*	-0.1965*	-0.0757	-0.0385
	(0.0904)	(0.0693)	(0.0846)
2008 * *IV_nlhhi*	-0.2011*	-0.1071	-0.0846
	(0.0993)	(0.0729)	(0.0945)
2003	0.0188	-0.0255	-0.0088
	(0.0329)	(0.0264)	(0.0412)
2004	0.0382	-0.1110***	-0.1357
	(0.0362)	(0.0278)	(0.0345)
2005	0.0582	-0.1727***	-0.2147
	(0.0588)	(0.0392)	(0.0598)
2006	0.0056	-0.2128***	-0.2448
	(0.0625)	(0.0573)	(0.0691)
2007	-0.0660	-0.2682***	-0.2781
	(0.0731)	(0.0578)	(0.0689)
2008	-0.1427	-0.3137***	-0.2973
	(0.0815)	(0.0678)	(0.0826)
IV_nlhhi	-0.5529	0.6090	1.3625
	(1.0543)	(0.7788)	(0.9719)
Hospital Fixed Effects	Yes	Yes	Yes
N	1518	1518	1518
R2	0.67	0.78	0.70

Patient characteristics: average annual patient age; average annual patient socioeconomic status measured using the income component of the 2007 Index of Multiple Deprivations; patient gender; and average annual patient Charlson comorbidity score.

Hospital characteristics: Number of procedures carried out at each hospital annually; annual hospital 30-day hip replacement mortality; and annual hospital 30-day readmission rate.

Standard errors are clustered on hospital sites.
* Significant at 5% level; ** Significant at 1% ,*** Significant at 0.1%

Figure 1: A timeline of key NHS reforms from 2002 through 2008

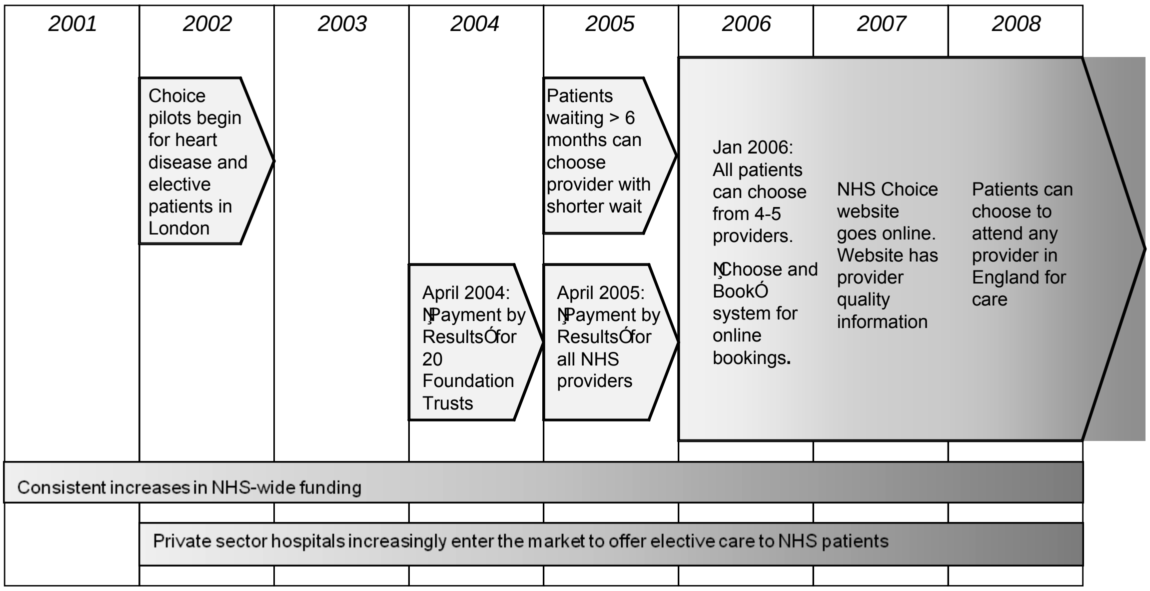


Figure 2: Trends in pre-surgery LOS, overall LOS and post-surgery LOS from 2002 through 2008

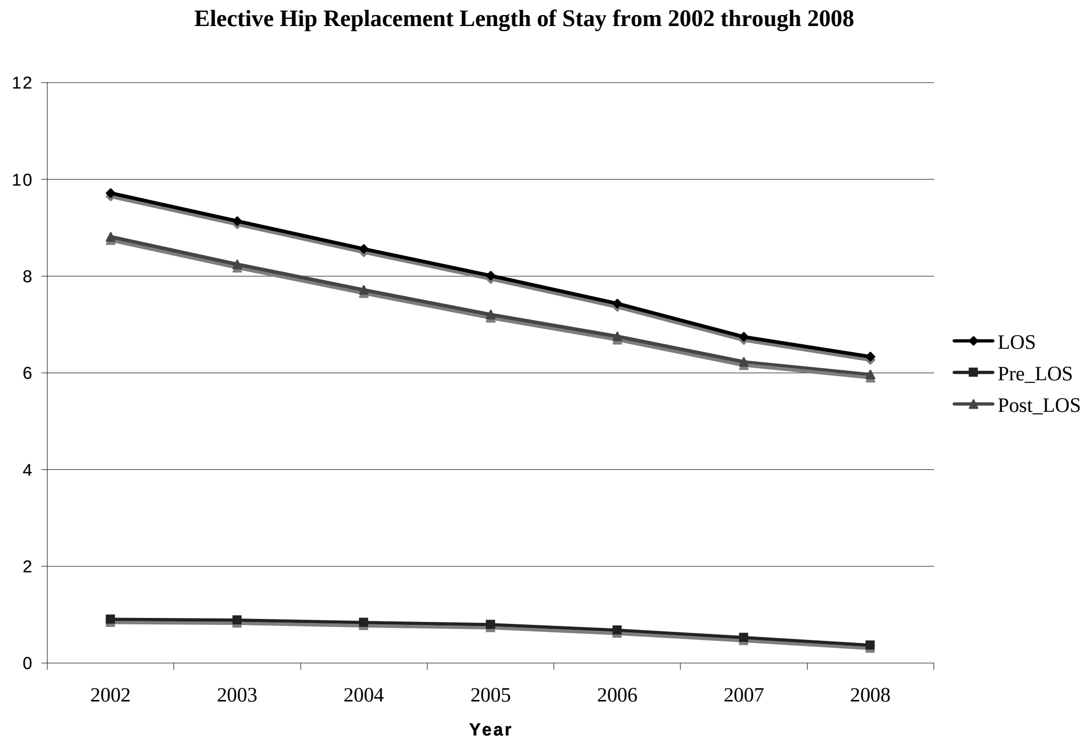


Figure 3: Trends in overall LOS for the most competitive, somewhat competitive and least competitive hospitals

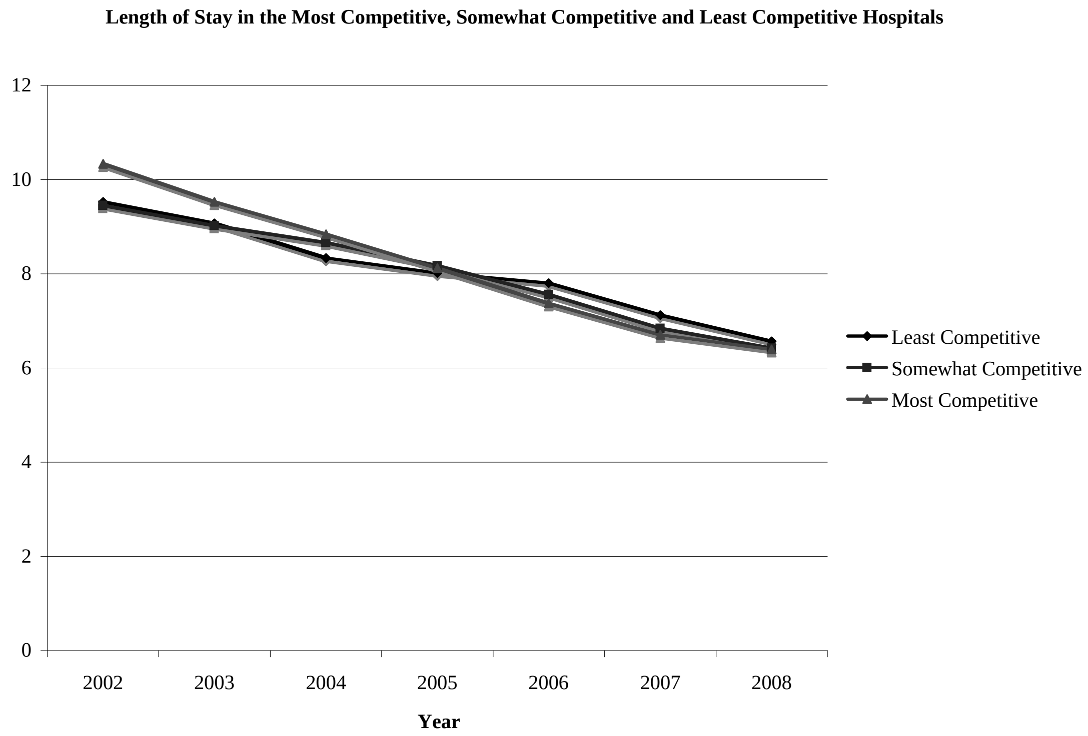


Figure 4: Trends in pre-surgery LOS in the most competitive, somewhat competitive and least competitive hospitals

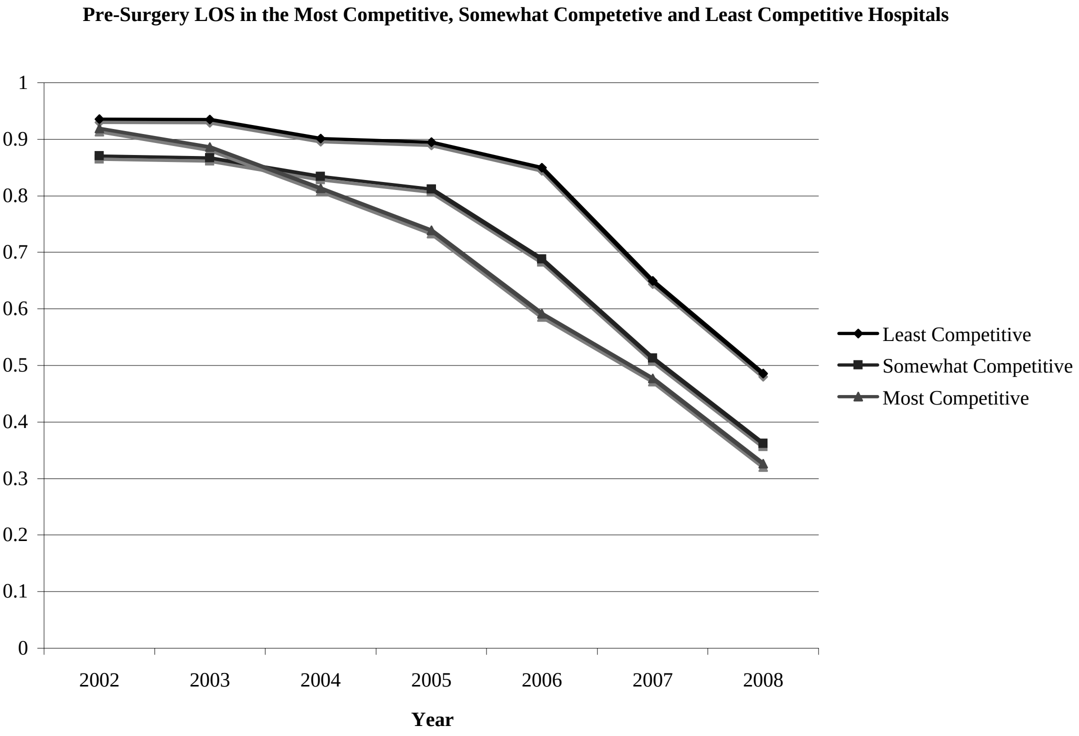
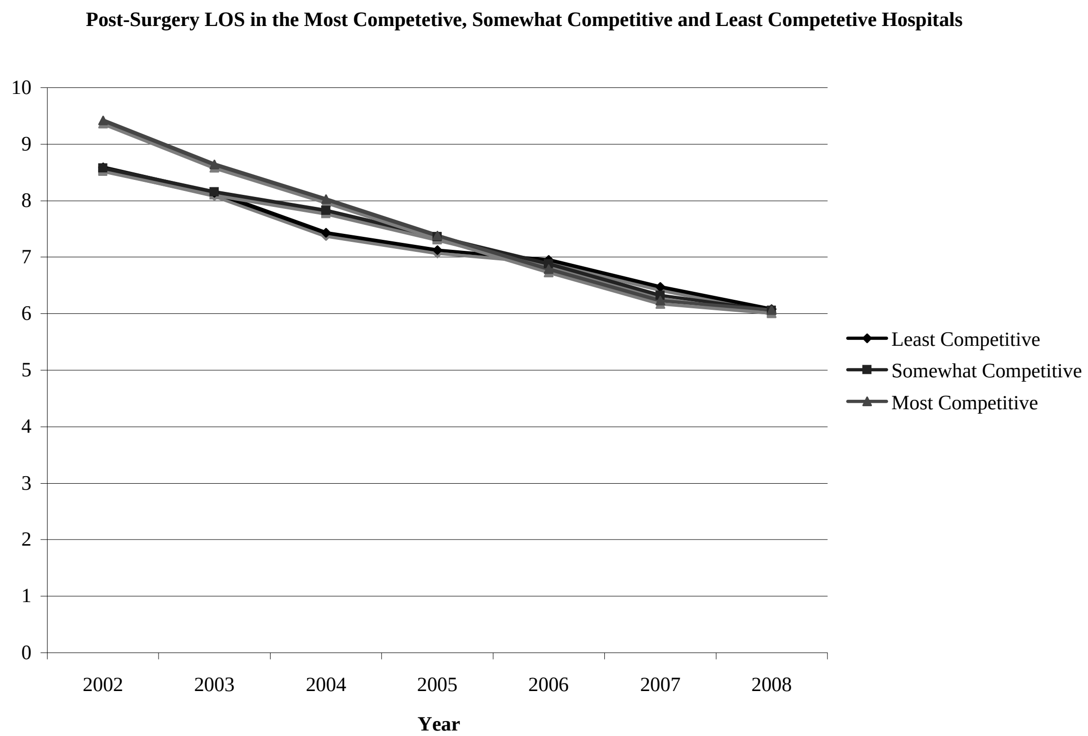


Figure 5: Trends in post-surgery LOS in the most competitive, somewhat competitive and least competitive hospitals



Appendix

Appendix 1: Summary statistics for key variables						
Variable Name	Description	Obs.	Mean	Standard Dev.	Min	Max
IMD2007 Income Vector	Hospital's Annual Average of Patients' Income vector of the 2007 Index of Multiple Deprivations	1518	2.8981	0.6072	1.0000	5.0000
Charlson Comorbidity Score	Hospital's Annual Average of Patients' Charlston Charlson Co-Moridity Score	1518	0.2545	0.2388	0.0000	6.0000
Female	Percentage of Hospital's patients That are Female	1518	0.6168	0.0884	0.0000	1.0000
Readm28	Hospital's Annual Average 28-day Readmission Rate	1518	0.0689	0.0611	0.0000	1.0000
Deathall30	Hospital's Annual 30-day Mortality Rate	1518	0.0052	0.0096	0.0000	0.2000
LOS	Hospital's Average Annual LOS	1518	8.3823	1.9656	0.0000	22.0000
Pre-surgery LOS	Hospital's Annual Pre-Surgery LOS	1518	0.7332	0.4131	0.0000	4.0000
Post-Surgery LOS	Hospital's Annual Post-Surgery LOS	1518	7.6491	1.8247	0.0000	22.0000
Site_Activity	Number of Hip Replacements Performed per site per year	1517	240.3396	165.4844	30.0000	1147.0000
Negloghhi95_2002_2005	The negative log of the HHI measured in a variable radius market averaged across 2002-2005	1518	0.7901	0.4165	0.1007	2.1696
G_count_95sh	Count of hospitals within a variable radius market averaged across 2002 - 2005	1518	6.1451	4.1225	1.5215	21.8977

Appendix 2: Full results for least-squared estimates of (5) with competition measured as the negative log of the HHI in a 95% variable radius market and pre-surgery LOS as the dependent variable

nlhhi	-0.1165	0.2184
2003 * *nlhhi*	-0.0273	0.0191
2004 * *nlhhi*	-0.0379	0.0281
2005 * *nlhhi*	-0.0681	0.0402
2006 * *nlhhi*	-0.1024*	0.0413
2007 * *nlhhi*	-0.1195*	0.0479
2008 * *nlhhi*	-0.1037*	0.0518
2003	0.0126	0.0147
2004	-0.0031	0.0227
2005	0.0170	0.0334
2006	-0.0350	0.0346
2007	-0.1270*	0.0416
2008	-0.2269***	0.0476
Comorbidity Score	0.0487	0.0444
Age	-0.0004	0.0105
IMD2007_Income	0.0103	0.0513
Site_Activity_150_300	-0.0244	0.0184
Site_Activity_300_450	-0.0369	0.0264
Site_Activity_450+	-0.0784	0.0492
28-Day Readmission Rate	-0.0981	0.2260
30-Day Mortality Rate	1.2360	0.7646
Average Distance Travelled	0.0000	0.0000
% Female	0.1612	0.1366
Obs	1518	
R2	0.069	

Patient characteristics: average annual patient age; average annual patient socioeconomic status measured using the income component of the 2007 Index of Multiple Deprivations; patient gender; and average annual patient Charlson comorbidity score.

Hospital characteristics: Number of procedures carried out at each hospital annually; annual hospital 30-day hip replacement mortality; and annual hospital 30-day readmission rate.

Standard errors are clustered on hospital sites.
* Significant at 5% level; ** Significant at 1% ,*** Significant at 0.1%

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